Residual Dynamics in Hydrological Models: Insights from a large sample of catchments and models

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Abstract

Residuals from hydrological models are critical for evaluating model performance, improving predictive accuracy, and deepening the understanding of hydrological processes. Enhancing predictive methods is especially crucial for capturing extreme events, which have significant implications for risk management and planning. These residuals, however, are influenced by model structures, preprocessing methods, and catchment characteristics. This study addresses these complexities by systematically analyzing the statistical properties of residuals under various transformations and preprocessing treatments. The analysis spans a diverse dataset of catchments across a broad range of hydroclimatic conditions, with residuals generated from simulations of multiple hydrological models, ensuring both the generality and robustness of the findings.

Key aspects of the research include the evaluation of residual properties under transformations, such as log-transformation, and the role of preprocessing steps. Through this approach, the study provides a more consistent framework for assessing variability, skewness, kurtosis, autocorrelation, and dependency structures in residuals. Additionally, the analysis encompasses heteroskedasticity and tail dependencies, capturing the nuances of residual behavior across different contexts.

The dataset's extent is a defining strength of this study. By involving simulations from a wide range of hydrological models (78 configurations) and including catchments with varying climatic and physical characteristics (more than 400 basins in the United States, ranging from dry to wet climates), the research delivers insights that are widely applicable to diverse hydrological conditions. This breadth ensures that findings are relevant for both theoretical advancements and practical applications, offering guidance to researchers and practitioners working with different modeling systems and catchment types.

A central result highlights the transformative impact of removing seasonality from residuals. De-seasonalization not only stabilizes key residual properties but also reduces variability across models, facilitating a clearer evaluation of model performance and error structures, underscoring the importance of standardizing preprocessing techniques in hydrological modeling, as it enables more robust and interpretable diagnostic frameworks. A direct consequence of residual analysis is then the development of stochastic models for uncertainty estimation as well as the possible development of alternative objective metrics to calibrate rainfall-runoff models.